GATHERING PHOBOS REGOLITH FROM A MARTIAN SATELLITE ORBITING NEAR THE LAGRANGE POINTS

M. Hamelin, *Centre d'etude des Environments Terrestre et Planetaires (CETP), CNRS, 4 Avenue de Neptune, F-94107 Saint Maur Cedex, France, Email:michel.hamelin@cetp.ipsl.fr*

ABSTRACT

The collection of samples from the Phobos regolith and their return to Earth for chemical and mineralogical analysis has a great scientific and logistic interest. In particular dating the samples by the measurement of isotopic ratios would be a key for the study of the origin of this martian satellite: accreted in martian orbit or captured ? What are the indigeneous ressources as oxygen or water that could facilitate future Mars manned missions ? An alternative to send a spacecraft on the surface of Phobos and to launch back the samples would be gathering directly the samples from a Mars orbiter using a 'fishing line'. Ballistic trajectories are computed to show the validity of this mission scenario.

1. INTRODUCTION

The Martian satellites Phobos and Deimos were getting a wide attention in the last eighties with the ambitious soviet mission PHOBOS. Phobos was approached by one of the two spacecraft but both failed to perform the very close flypasts, at an altitude of 50 m, that were foreseen to analyse the surface material. Fifteen years were spent without any other attempt although the interest is still present. Even with improved instruments, the in situ analysis would hardly reach the same accuracy than in the laboratory. For mass specrtometry for instance, the required mass resolution to measure critical isotopic ratios is a few thousands, and such instruments are still delicate and heavy. With the improvements of navigation and re-entry techniques, the collection of samples and return to Earth for laboratory analysis is now envisaged with the landing of a spacecraft on Phobos [1]. However, as only small amounts of material are needed for laboratory analysis, it would be also possible to gather the samples from a Mars orbiter, avoiding the risky landing and launching operations from an unknown site on Phobos (or Deimos). After pointing out the interest of Phobos investigations, I will discuss the dynamic aspects of the 'fishing-line technique, and also a variant, the 'anchoring technique'.

2. SCIENTIFIC AND LOGISTIC INTEREST OF PHOBOS EXPLORATION

2.1 Scientific interest

Phobos and Deimos are clues of the early solar system formation as their small size protected them against internal heating and tectonic activity. They have been exposed to metoritic gardening and to solar wind particles implantation in the first nanometers of their regolith grains. They are either asteroids captured by Mars as currently assumed [2] or they are built by accretion of debris. From their spectral characteristics the surface material looks like carbonaceous chondrite. The mean density is ~ 1900 kg m-3, much less than Mars' mean density of 3900 kg m-3 and much less than carbonaceous chondrite. Ice could be present inside Phobos at a depth of a few hundred meters [3,4]. Phobos is different from Deimos: its distance to Mars, close to the Roche limit, is decreasing with time. It is then exposed to intense increasing tidal forces [5]. Chemical and mineralogical analysis of samples of the surface material, with measurement of isotopic ratios would provide essential information about the origin and history of Phobos. This objective is accessible as Phobos is energetically easier to reach than the moon, for which automatic sample return missions were performed by the Luna's in the late sixties !

2.2 Logistic interest

For far future Mars explorations, Phobos could play an important role as a Mars 'posting house' providing radiation shielding in Mars orbit and material supply. Aerobraking can be used to land on Mars, but for the return to Earth indigeneous fuel supply could be used, extracted from Phobos for the interplanetary flight. Most of the the fuel in weight (as O_2) could be produced from Phobos material. Water could be present, as buried ice or as water molecules bounded to minerals, then providing both O_2 and H_2. The thick regolith layer on Phobos could be used as a shield against radiations for human explorers. Moreover remote exploration of Mars could be managed from

Phobos; piloting rovers in quasi real time is an example.

3. FLIGHT DYNAMICS CLOSE TO THE PHOBOS LAGRANGE POINTS

3.1 Gravitationnal environment

Phobos as a few small satellites in the solar system is orbiting around its primary inside the Roche limit and its rotation is synchronous with its orbital motion. A simple model will describe the gravitationnal environment. Following the same approach than in [6] , the model will describe the motion of a material point around an ellipsoidal homogeneous body in synchronous rotation around a spherical homogeneous primary. This circular restricted three-body problem applies also to Deimos. Velocity curves derived from this gravitational model are shown in Fig. 1 for the Table 1 parameters.

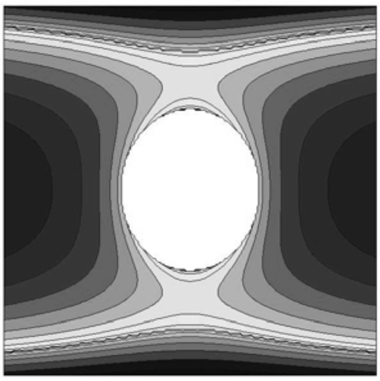

Fig. 1. Velocity curves around Phobos, with 1 m/s intervals. Mars is far away towards the top.

Half large axis	12940 m
Half medium axis	11000 m
Half small axis	9220 m
Density	1900 kg / m3
Angular velocity	2.28 e-4 rd / s
Distance center Mars – center Phobos	9370 km

Table 1. Parameters of the dynamical model

The Lagrange points L1 and L2 are at only ~4.3 km from the surface. They are saddle points for the pseudo-potential. Here a Mars orbiter would be motionless but unstable in the Phobos-Mars direction. Two strategies are:

- ‘fishing’: a collecting device attached by a wire is thrown from the orbiter to the surface and hoisted back.

- ‘anchoring’: an anchor is thrown on the surface. The orbiter anchored to the surface will stay in stable equilibrium if away from L1 or L2. Samples could be lifted along the line.

3.2 The ‘fishing technique’

Strategy and constraints. The Mars orbiter is assumed to reach L2 in a first step (the case of L1 is similar). Then it will throw the sample collecting device in direction of Phobos, uncoiling the line that keeps the connection. Due to the mechanical impulse, the orbiter moves off in the opposite direction with the additional contribution of the pseudo-gravitational gradient. The collecting device hits the Phobos surface, catching regolith samples that are immediately hoisted up by the orbiter. The recovery would be a delicate operation, but the fact that the orbiter is accelerated away would facilitate the ascent of the sample container. I will study here only the downleg motion of the collecting device and the simultaneous recoil of the orbiter, to show the velocity and time constraints of this technique.

Starting position. It will be wise to fix the starting position at some distance from L2 towards Mars to avoid any risk for the orbiter to fall on Phobos. This distance should be larger than the uncertainty about the real L2 position, but not too large otherwise the orbiter would move away very rapidly. Here, 3 distances from L2 are used as examples: L2-200 m that is the current precision of radar altimeters, L2-400 m to show what are the constraints risen by a larger safety distance, and L2 itself.

Trajectories. In the following model the collecting device mass is assumed to be 1% of the orbiter mass, for instance 5 kg with respect to 500 kg. The trajectories are shown in Fig.2 and their main characteristics are shown in Table 2.

initial velocity (m/s)	1 (a)	2 (b)	4 (c)
time of flight (s)	3113	1932	1073
trajectory length (m)	6057	5293	4830
distance (m)	6014	5245	4800
orbiter recoil (m)	774	284	112
impact velocity (m/s)	3.58	4.01	5.32
longitude (°)	9.74	7.53	4.65
angle (velocity, surface)°	53.23	53.92	62.12

Table 2. Characteristics of the descent trajectories shown in Fig. 2, and orbiter recoil.

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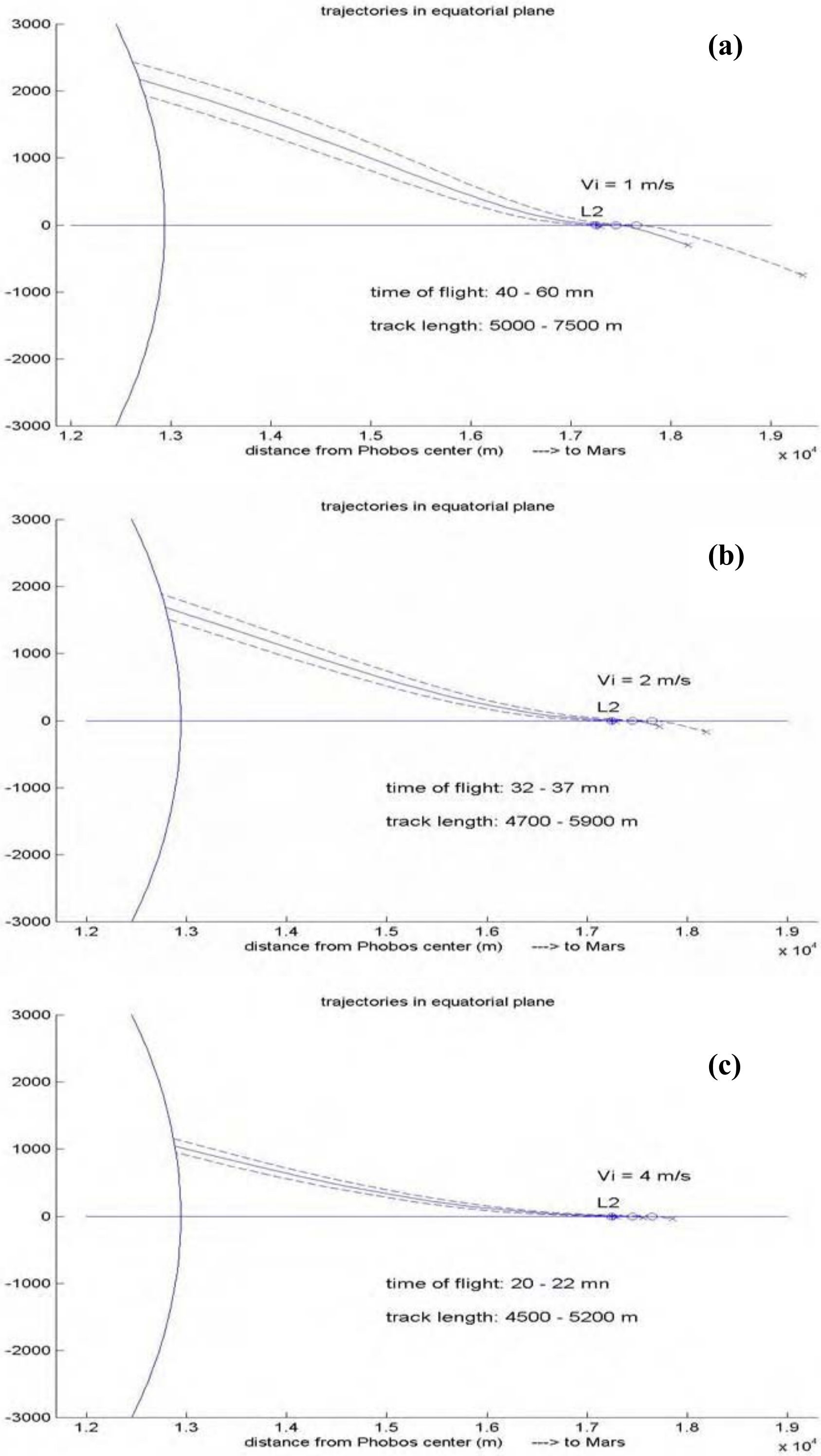

Fig. 2. Trajectories of the collecting device and orbiter recoil for three separation velocities: 1 m/s (a); 2 m/s (b); 4 m/s (c). Starting positions: o; ends of recoils: x.

All trajectories are strongly deviated from the initial line of sight due to the fast rotation of Phobos. They will hit the surface with slanting angles. For initial velocities of 1-2 m/s, the velocity to surface angles are 53-54°. A velocity of 4 m/s is needed to increase this angle to 62°. This angle is a constraint for the sample-collecting device that should work under oblique impact with the surface. For small initial velocities as 1 m/s, the track length is long (5-7.5 km), and the orbiter recoil increases it, especially if the starting position is L-400m. It seems more favourable to eject the collection device with a relatively high velocity. With 4 m/s, the track length is 4.5-5.2 km, no much more than the straight distance 4.3 km. The impact velocity is 5.3 m/s instead of ~3.6 m/s for the 1 m/s initial velocity, but this is not a disadvantage as this kinetic energy could be useful to collect the regolith samples.

3.2 The 'anchoring technique'

The saddle configuration of the gravitational potential near the Lagrange points allows a particularly unusual possibility to hold a spacecraft in a fixed stable position behind a L1 or L2 Lagrange point with a line anchored on Phobos. In this situation, at L2-1000 m for instance, the tense of the line would be only 0.24 N for a 500 kg orbiter ! It should be anchored on the surface (by a harpoon or balanced by a mass slightly greater than ¼ of its own mass). Then a shuttle could run along the line between the surface and the orbiter. The trajectory for the descent has been computed for an L2-1000 starting point, 8 m/s initial velocity and 0°, 5° and 10° launch angles (Fig. 3). Thus it is possible to aim at the apex of the Phobos ellipsoid.

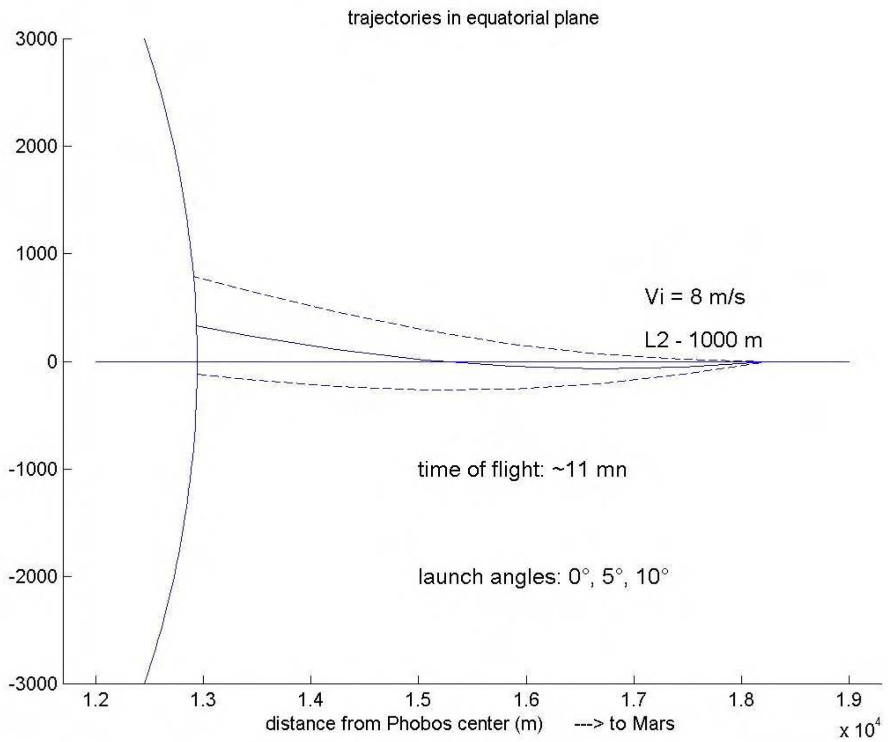

Fig. 3. Trajectories of the tethered descent module from L2-1000 m, with 3 starting angles: 0°, 5° and 10°

4. DISCUSSION

It has been shown with the computed trajectories that the jettisoning and descent of a tethered module from L2 (or L1) on the surface of Phobos is possible from a dynamic point of view. The starting points were assumed to be at 200-400 m from L2, and it has been shown that larger distances from L2 would increase the length of the trajectory and decrease the incidence at impact. In fact Phobos is far from ellipsoidal as in the model. Its shape is well known, but it is probably inhomogeneous (unknown regolith depth, possible ice filled core). The close gravitational field cannot be deduced accurately from the visible geometry.

The PHOBOS spacecraft did not approached Phobos enough to provide more experimental data on the gravitational field. The real position of the Lagrange points is not known with the required secure accuracy of a few hundred meters. Such a descent scenario could be optimised if some prior Phobos lander would allow extending the current knowledge of the local gravitational field.
Concerning the technical aspects of the two techniques, the 'fishing' one is certainly lighter. Anchoring with a harpoon could be difficult on a thin regolith material and not reliable, so this option would be interesting if a relatively massive descent module (~1/4 of the orbiter mass) was sent on the surface. In that case a rover or crawler could explore the surface after the release of the sample container towards the orbiter.
Unrolling several km of line is usual for the guidance of small missiles. The technological difficulty would be to lift back the sample container with an adequate control of the line tense and to dock it in the return-to-Earth module.
The collecting device is also to be defined; it could use the impact kinetic energy to catch samples within a small depth range in the regolith.
In conclusion, gathering Phobos samples from a Mars orbiter should be possible with lighter means than with a Phobos lander. It would require some technical studies and if possible a better knowledge of Phobos's gravitational field. Once in Mars orbit the return mission will be similar to that of a Mars sample return.

5. REFERENCES

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